# FLASHOVER PERFORMANCE OF LIGHTNING PROTECTED BUILDINGS USING SCALED MODELS AND ELECTRIC FIELD ANALYSIS

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To my parents, family and friends for their endless and constant prayers and moral support

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## ABSTRACT

In early era, Benjamin Franklin discovered that the application of Lightning Rod (also known as the Franklin Rod) method is found to be effectived as a lightning protective device for buildings. Hence, it was considered among the best solution to overcome the problems facing by publics due to lightning strikes. However, few years later it was found that the corroded Franklin Rod due to the impact of environmental contaminations tends to reduce its ability to effectively capture the lightning strikes. The directly or indirectly impacts of lightning strikes had caused owners to spend huge amount of money just to repair damages on the buildings. Nowadays, there were many professional standards and documents guiding public to properly install the building's lightning protection system, yet the same damages problems had shown to be frequently occur that related to the strikes often bypasses the of Lightning Air Terminal (LAT) system. The main reason for this could be due to lacking ideas by learned circle of lightning experts as not to fully understand the behavior of Franklin Rods system when it interacts with the lightning leaders. Therefore, this thesis discusses the works that investigated the flashover performances occurred on the buildings with various structural geometry shapes. The case study method is using small scaled models for both laboratory and simulation works, aiming to understand the Franklin Rods performance on capturing lightning leaders. Summarizing the works, about 11 scaled-down building shape models equipped with Franklin Rods system are selected in the case studies such as follows; a conical, gable, triangular, half circle, L-shape, square, cylindrical, butterfly, pyramid, rectangular and inclined like shapes. These models were then injected with 30 lightning flashes each using the 100 $kV_{peak}$ single stage impulse generator. This number of flashes is considered as total two-years lightning activity frequencies in Malaysia, which the lighting flash density is statistically recorded to be around 15 flashes / year / $km^2$. The maximum applied voltage is about 86.5 $kV_{peak}$. The model scaling concept is based on 1:30 cm ratio for every 3 m height of building structure. Interestingly, the overall work data had shown that the pyramid-like shapes is found to be the best structure type to be used in reducing the LAT bypasses and direct strike damages. The structure's Franklin Rod protection system captured the least number of strikes during competitive tests conducted on all of the scaled down building models. Works of electric field analysis on all building models were conducted using ANSYS Maxwell simulation tool. Utilisation of electric field plot data in this work enables the creation of likelihood factor (ranging from 0.1 to 0.9) method that so useful to capable predict the strikes pattern occurring on dedicated terminal rod. Both laboratory and simulation work also confirm that the edge shapes play crucial roles as intense electric fields is found to accumulate on the edges area when the Franklin Rod intercepts the lightning leaders. These mentioned findings lead to introducing better method of LAT placement on the top of the building, whereby the existing lightning protection system is recommended to have one of installed LAT rods elongated to act as sacrificial point to directly attract lightning strikes. All the work and key findings in this work can contribute to the science and technology field toward having a better LAT lightning protection system and also lead to better decision in selecting / designing the shapes and edges concept as to reduce likelihood of LAT bypasses and damages of the building structure.

## ABSTRAK

Pada era awal, Benjamin Franklin mendapati bahawa penggunaan Rod Pemimpin Kilat (juga dikenali sebagai *Rod Franklin*) didapati berkesan sebagai alat pelindung kilat untuk bangunan. Oleh itu, ia dianggap antara penyelesaian terbaik untuk mengatasi masalah yang dihadapi oleh orang awam disebabkan pancaran kilat. Walaubagaimanapun, beberapa tahun kemudian didapati bahawa Franklin Rod yang berkarat akibat kesan pencemaran alam sekitar cenderung untuk mengurangkan keupayaannya untuk menangkap serangan kilat dengan efektif. Kesan langsung atau tidak langsung serangan kilat telah menyebabkan pemilik menghabiskan sejumlah besar wang hanya untuk membaiki kerosakan di bangunan. Pada masa kini, terdapat banyak piawaian profesional dan dokumen yang membimbing orang ramai untuk memasang sistem perlindungan kilat bangunan dengan betul, namun masalah kerosakan yang sama telah ditunjukkan sering berlaku yang berkaitan dengan serangan kilat yang sering melepasi sistem *Lightning Air Terminal (LAT).* Punca utama mungkin disebabkan oleh kekurangan idea di kalangan ahli penyelidik fenomena kilat yang tidak memahami sepenuhnya kelakuan sistem Franklin Rods apabila ia berinteraksi dengan pemimpin kilat. Oleh itu, tesis ini membincangkan kerja-kerja yang menyiasat persembahan *flashover* berlaku di bangunan dengan pelbagai bentuk geometri struktural. Kaedah kajian kes menggunakan model skala kecil untuk kedua-dua kerja makmal dan simulasi, bertujuan untuk memahami prestasi *Franklin Rods* dalam menangkap pancaran kilat. Merumuskan kerja, kira-kira 11 model bentuk bangunan berskala kecil pelbagai bentuk yang dilengkapi dengan sistem *Franklin Rods* dipilih dalam kajian kes seperti berikut; lingkaran kon, gable, segitiga, setengah bulatan, bentuk L, persegi, silinder, rama-rama, piramid, segi empat tepat dan bentuk cenderung. Kemudian model-model ini setiap satunya direnjat dengan 30 pancaran kilat menggunakan 100 $kV_{puncak}$. Jumlah renjatan ini dianggap sebagai kekerapan aktiviti kilat selama dua tahun di Malaysia, yang ketumpatan kilat cahaya dicatatkan secara statistik berada sekitar 15 pancaran / setahun / $km^2$. Voltan maxima yang digunakan adalah pada kadaran 86.5 $kV_{puncak}$.

Konsep pengecilan skala model berdasarkan nisbah 1:30 cm untuk ketinggian struktur 3 m setiap bangunan. Menariknya, data kerja keseluruhan menunjukkan bahawa bentuk seperti piramid merupakan struktur terbaik yang boleh digunakan untuk mengurangkan pintasan *LAT* dan kerosakan langsung pada permukaan bangunan. Struktur bentuk ini membolehkan sistem perlindungan *Franklin Rod* menangkap paling sedikit jumlah pancaran semasa ujian persaingan yang dilakukan pada semua model bangunan berskala rendah. Kerja-kerja analisis medan elektrik pada semua model bangunan telah dijalankan menggunakan alat simulasi *ANSYS Maxwell*. Pemanfaatan data plot medan elektrik dalam kerja kami membolehkan penciptaan kaedah faktor kemungkinan (dari 0.1 hingga 0.9) yang amat berguna digunakan untuk meramalkan corak pancaran yang berlaku pada rod terminal khusus. Kerja-kerja makmal dan simulasi juga mengesahkan bahawa bentuk pinggir pada sesebuah struktur bangunan memainkan peranan penting di mana medan elektrik yang kuat dijumpai berkumpul di kawasan pinggir struktur bahan apabila *Franklin Rod* memintas cahaya kilat utama. Penemuan-penemuan yang disebutkan di atas membawa kepada kaedah penempatan *LAT* yang lebih baik di bahagian atas bangunan, di mana sistem perlindungan petir sedia ada disyorkan untuk mempunyai satu rod *LAT* yang dipasangkan lebih panjang untuk bertindak sebagai punca utama bagi menarik perhatian pancaran kilat. Semua kerja dan penemuan penting dalam kerja ini boleh menyumbang kepada bidang sains dan teknologi ke arah mempunyai sistem perlindungan kilat *LAT* yang lebih baik dan juga membawa kepada keputusan yang lebih baik dalam memilih / merekabentuk konsep bentuk dan pinggir objek bagi mengurangkan kemungkinan perlepasan jangkauan *LAT* dan kerosakan pada struktur bangunan.

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